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OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

1953 ROCHESTER MEETING

AT

ROCHESTER, NEW YORK

June 18–19–20, 1953

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JUNE 18, 1953 Vol. 28, No. 4

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1953 JUNE MEETING AT ROCHESTER, NEW YORK, JUNE 18–19–20, 1953

THE 1953 June meeting of the American Physical Society—the Summer Meeting in the East—will be held at Rochester, New York, on the River Campus of the University of Rochester, on Thursday, Friday, and Saturday, **June 18, 19, and 20, 1953.** This meeting will appeal to many as being of the ideal size—not so small as to humiliate the host institution, not so huge as to suffocate those who attend it with a surfeit of papers. After the formidable meetings of January, March, and April of this year, this will furnish a welcome contrast! We are indebted to R. E. Marshak and J. B. Platt for planning the major groups of invited papers in nuclear physics, and also Session I; and to K. G. McKay, delegated by the Division of Electron Physics to organize the programme of invited papers in electron physics (let the solid-state physicists not cavil at the use of this term for topics that they may deem to be in their field!). J. B. Platt is the Chairman of the Local Committee.

As stated in the North Carolina Bulletin, the reservations of rooms should be made—or rather, by this time should have been made—by writing to the Hotel Seneca. To go from the Seneca to the scene of the meetings, walk to the corner of Main and Clinton streets (half a block) and board the bus marked "Plymouth ave. to U. of R. Campus." Allow forty minutes for the journey. However, the Local Committee will provide a special bus from the Seneca to the River Campus if it can.

The **registration desk** will be set up in the lobby of Strong Auditorium. Members and guests are asked to register, and to pay a **registration fee** of one dollar; and they are advised to keep an eye on the adjacent bulletin boards for notice of messages.

On Thursday morning there will be a Symposium on nuclear models, followed by a discussion; and on Saturday morning, a Symposium on nuclear reactors. The speakers are V. F. Weisskopf, J. A. Wheeler, and A. de-Shalit in the former, J. J. Grebe, W. K. Ergen, Lewi Tonks, and W. B. Lewis in the latter. On Friday morning there will be a group of invited papers, F. Seitz and L. P. Smith speaking on solid-state physics (we will not confer the term "electron physics" upon these!), Julian Webb and Franz Urbach on photographic processes. On the general programme appear also invited speeches by K. R. Atkins, H. E. Duckworth, J. S. Foster, K. C. D. Hickman, W. Kohn, and H. L. Welsh. Speakers invited by the Division of Electron Physics are distributed into a group of four (E. W. Mueller, J. A. Becker, Robert Gomer, and W. P. Dyke) lecturing on field emission; a group of three (J. F. Marshall, A. van der Ziel, and J. J. Lander) devoted to secondary electron emission, and two others (David Sternberg and H. D. Hagstrum) talking of the transaction between metals and impinging ions and atoms.

Seventy-six contributed papers are assigned to eleven sessions. This is one of the smaller meetings, and so there are numerous papers almost or quite isolated in their respective fields, so that their placing may appear rather odd. Thanks are expressed to K. G. McKay for helping with the sorting of the nonnuclear papers. The terms "Upper Strong Auditorium" and "Lower Strong Auditorium" have nothing to do with the relative strengths of the papers assigned to them.

The **banquet** of the American Physical Society will be held on Friday evening at seven in the Hotel Seneca. The price will be $3.85. In accordance with the custom at our Summer meetings, attire should be informal. Advance reservations should be made by use of the form on the inside back-cover page. The after-dinner speaker will be W. A. Noyes, and his topic "How Are We Training Our Scientists?"

Banquet tickets will be sold at the registration desk: members should look at the bulletin boards to learn the deadline for purchase of tickets. Luncheon tickets, for meals in the Student Union, will also be available at the desk. **Tours** of the laboratories of Eastman Kodak Company, Bausch and Lomb Company, and the University of Rochester will be organized for those who apply at the desk. Arrange-

ments are being made for the **entertainment of ladies.**

The **Bausch and Lomb Optical Company,** which is celebrating its centennial anniversary, invites our members for cocktails at the Hotel Seneca on Friday afternoon, preceding the banquet, from 5:30 to 7:00 P.M. The **University of Rochester** invites our members to participate in a punchbowl party on the campus quadrangle on Thursday afternoon at 5:00 P.M.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received not later than Friday, June 12, at the office of Professor R. E. Marshak, University of Rochester, Rochester 3, New York. The titles of such papers as may be accepted will be announced on a blackboard near the registration desk, and the papers will be given under the usual ten-minute rule at the end of Session J.

The **Council** will meet at 9:30 A.M. on Saturday in the Welles-Brown room of the Rush-Rhees Library on the River Campus, unless contrary notice is sent to its members. This is expected to be a very short meeting.

For **prospective meetings** of the Society and the corresponding deadlines, see page 5 of this bulletin.

Titles and abstracts of the papers contributed to the 1953 Rochester meeting are printed hereinafter, and in exactly this form they will appear in a future issue of *The Physical Review.* Errata will be printed on an adjacent page of *The Physical Review* if received not later than Friday, July 3, by Miss Ruth Bryans, American Institute of Physics, 57 East 55th street, New York 22, New York. Do not send in the abstract marked with corrections: write out the corrections in the form "instead of . . . read. . . ." Add nothing.

KARL K. DARROW, *Secretary,*
American Physical Society,
Columbia University,
New York 27, New York

This Is the Summons-Card for the 1953 Thanksgiving Meeting

The 1953 Thanksgiving meeting of the American Physical Society will be held at Chicago, in the buildings of the University of Chicago, on Friday and Saturday, November 27 and 28, 1953. It will be a pleasure to our members to revert to the tradition of holding the Thanksgiving meeting at the University of Chicago, an old tradition which since World War II has been more honored in the breach than in the observance. For hotel accommodations write to Hotels Windermere, 1642 East 56th Street, Chicago 37, Illinois. If it is overlooked, it will see to getting you a reservation elsewhere. Mention in your letter that you belong to the American Physical Society.

Deadline Day Will Be Friday, September 25

Abstracts of papers contributed to the Chicago meeting are to be sent to the address below, which they must reach not later than Friday, September 25. Send two double-spaced typewritten copies, original and carbon (not a pair of carbons). Remember that an abstract must not be longer than 200 words or the equivalent thereof. In reckoning equivalence, a "display formula" (one that must occupy a line or more by itself) is an expensive luxury equated to 40 words; each line in a table counts as ten words, each footnote as ten words. Confine each abstract to a single page.

KARL K. DARROW, *Secretary,*
American Physical Society,
Columbia University,
New York 27, New York

(Please keep this page on file!)

MEETINGS AND DEADLINES FOR THE SEASON 1953–1954

Ideally the deadline-to-meeting interval should be so chosen as to minimize the sum of two evils. One of these derives from the fact that the earlier the deadline, the greater the number of results that fail to be ready in time for presentation at the meeting. The other is due to the fact that the later the deadline, the later the Bulletin reaches our members, and the greater the number of these who cannot make plans for travel after they know the programme of the meeting. If it be true that silence gives consent, more than 95 percent of the members of the American Physical Society are satisfied with deadlines and Bulletins as late as those of the season just ending. Yet it does seem as though we had yielded too far to those who prefer late deadlines, to the displeasure of those who prefer early Bulletins. The Council has authorized the lengthening of the deadline-to-meeting interval to ten weeks. This will be done for the New York and Washington meetings of 1954, also for the West Coast meeting of the holiday week (not because we apprehend an enormous size for this convention, but because it is disadvantageous to entrust the Bulletin to the mails during the pre-Christmas rush). For the Thanksgiving and the March meetings, the interval will be nine weeks; for the Austin and the Minneapolis meetings, eight weeks.

I. Meetings east of the Rockies

Place	*Meeting dates*	*Deadline dates*
Chicago	November 27–28, 1953	September 25
New York	January 28–30, 1954	November 20
Austin	February 26–27	December 30
Detroit-Ann Arbor	March 18–20	January 15
Washington	April 29–30, May 1	February 19
Minneapolis	June 28–30	April 30

Abstracts of contributed papers for the foregoing meetings are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York. To avoid danger of confusion, please do not send abstracts for any meeting until the deadline date of the previous meeting is past.

II. Meetings west of the Rockies

Albuquerque	September 2–5, 1953	July 1
Stanford	December 28–30, 1953	October 19
Seattle	July 7–10, 1954	May 5, 1954

Abstracts of contributed papers for these three meetings are to be sent to J. Kaplan, University of California, Los Angeles 24, California.

EPITOME OF THE 1953 ROCHESTER MEETING

(Personal names are those of invited speakers)

Thursday Morning

A. Weisskopf, Wheeler, de-Shalit; discussion. Upper Strong.
B. Marshall, van der Ziel, Lander; secondary electron emission. Lower Strong.
C. Liquid state; solid-state physics, I. Biology.

Thursday Afternoon

D. Solid-state physics, II. Kohn. Biology.
E. Sternberg, Hagstrum; electron physics. Lower Strong.
F. Duckworth; nuclear masses, radioactive substances. Upper Strong.

Friday Morning

G. Atkins; cryogenics; Welsh; optical physics. Lower Strong.
I. Seitz, L. P. Smith, Webb, Urbach. Upper Strong.
J. Interactions of high-energy protons; nuclear energy levels. Biology.

Friday Afternoon

M. Foster, Oxley; nuclear physics. Upper Strong.
N. Mueller, Becker, Gomer, Dyke; field emission. Lower Strong.
P. Hickman. Biology.

Friday Evening

Banquet of the American Physical Society. Hotel Seneca. After-dinner speaker: Noyes.

Saturday Morning

Q. Grebe, Ergen, Tonks, Lewis. Upper Strong.
R. Cosmic rays; theoretical physics. Biology.
S. Solid-state physics, III. Lower Strong.

PROGRAMME

THURSDAY MORNING AT 10:00

Upper Strong Auditorium

(H. W. FULBRIGHT presiding)

Nuclear Models

A1. The Cloudy Crystal Ball Model. V. F. WEISSKOPF, *M.I.T.* (30 min.)
A2. The Collective Model. J. A. WHEELER, *Princeton University.* (30 min.)
A3. The Shell Model. A. DE-SHALIT, *M.I.T.* (30 min.)
Discussion to be led by M. GOLDHABER, G. SCHARFF-GOLDHABER, E. B. PAUL, AND KEITH BOYER.

THURSDAY MORNING AT 10:00

Lower Strong Auditorium

(K. G. McKAY presiding)

Secondary Electron Emission

B1. Theory of Secondary Emission. J. F. MARSHALL, *Bartol Research Foundation.* (30 min.)
B2. The Theory of Secondary Electron Production for a Screened Coulomb Interaction. A. VAN DER ZIEL, *University of Minnesota.* (30 min.)
B3. Auger Peaks in the Energy Spectra of Secondary Electrons from Various Materials. J. J. LANDER, *Bell Telephone Laboratories.* (30 min.)

Contributed Papers

B4. Average Energy of Electrons Emitted from Metals under High Energy Electron Bombardment. JOHN H. ANSON, KENNETH A. WRIGHT, AND JOHN G. TRUMP, *M.I.T.*—Measurements have been made of the average energy of the secondary electrons emitted from thick targets of C, Al, and Pb bombarded by 2 and 3 million volt electrons and of the ratio of secondary to primary electron current. The average secondary electron energy was determined as the difference between the incident electron energy and the sum of the calorimetrically determined heat energy in the target material and the calculated x-radiation. For 2-Mev primaries the secondary electron emission from Pb approaches 60 percent of the primary electron current and carries away nearly 30 percent of the incident energy. For Al the emission ratio is 15 percent and the energy ratio is 4 percent. The application of this information to phenomena at the anode end of high voltage acceleration tubes and to an instrument for electron dosage control will be discussed.

B5. The Role of the Surface Barrier in Secondary Emission from Metals. E. M. BARODY, *Battelle Memorial Institute.*—In secondary emission the transfer of momentum between the interacting primary and secondary electrons on the one hand and the metal as a whole on the other plays an essential part. In theoretical work this transfer has been introduced in various ways. According to Vyatskin,[1] the bulk of the observed emission is a nonclassical surface phenomenon caused by the potential energy rise at the metal surface. In the quantum-mechanical treatment of the problem, this leads to a momentum transfer which would not have been expected on classical grounds. We have made a study of Vyatskin's articles, particularly the earlier ones, which develop a theory based on Sommerfeld's model, and similar to Mitchell's 1934 theory of the surface photoelectric effect. This study has led to the conclusion that Vyatskin's effect exists in principle but [illegible] it is extremely small, making a negligible contribution to the total emission.

[1] A. Ya. Vyatskin, J. Exptl. Theoret. Phys., U.S.S.R., **9**, 826 (1939); **9**, 1049 (1939); **12**, 22 (1942); **20**, 547 (1950).

B6. Secondary Electron Emission from Diamond. J. B. JOHNSON,* *Bell Telephone Laboratories.*—Secondary electron emission was measured on a diamond which Ahearn[1] had previously studied as an α-particle counter. The clear cleavage plate, 0.2 mm thick and 7 mm on a side, was bombarded with short pulses of focused electrons for the secondary emission measurements. Charging effects were avoided by using small currents, low duty cycle, and heat when needed. The maximum δ varied in repeatable contours over the surface from 2 to 3.5. There was no clear correspondence of this pattern with the counting efficiency contours of Ahearn. Thus here the pattern is determined by the surface properties of the target, while the conductivity pattern is set by the volume properties. The average δ measured by defocused beam at room temperature had a maximum of 2.8 at 750 volts and was 1.7 at 5000 volts. At 750°C the yield was substantially reduced at and above 750 volts, as observed also with MgO.[2] This signifies that at the higher temperature the energy of the internal secondaries is more rapidly reduced below the escape level by the increased lattice vibrations.

* Now at Edison Laboratory, West Orange, New Jersey.
[1] A. J. Ahearn, Phys. Rev. **84**, 798 (1951).
[2] J. B. Johnson and K. G. McKay, "Secondary Emission of Crystalline MgO" (to be published).

SESSION C

THURSDAY MORNING AT 10:00

Biology Lecture Room

(J. H. HOLLOMON presiding)

Liquid State; Solid State Physics, I

C1. Proton Magnetic Resonance in Liquid Crystals. P. L. JAIN, H. A. MOSES, J. C. LEE, AND R. D. SPENCE, *Michigan State College.*—We have studied the proton resonance line in several liquid crystals. In the liquid phase of *p*-azoxyanisole, *p*-azoxyphenetole, and anisaldazine the line is narrow but on passing into the liquid crystal phase the line splits into three components whose separation is the order of one gauss between components. The separation between satellite lines increases as the temperature of the liquid crystal phase is lowered. The central component remains larger than the satellites throughout the liquid crystal phase of *p*-azoxyanisole and anisaldazine, while in the *p*-azoxyphenetole the central component gradually shrinks down to the level of the satellites as the temperature is reduced. In all three cases the sharp structure disappears in the solid state. The resonance lines of the liquid crystal phases of cholesteryl benzoate and sodium oleate and sodium stearate showed no structure.

C2. The Rotation of Microwave Polarization in Liquid Crystals in a Transverse Magnetic Field. GLEN A. MANN AND R. D. SPENCE, *Michigan State College.*—Previous experiments[1] on the effects of a magnetic field on the complex dielectric constant of liquid crystals at microwave frequencies indicate that such substances should be capable of producing a rotation of the plane of polarization in a circular wave guide placed in a transverse magnetic field. Investigations of this rotation are reported in this paper. The rotation appears to result from two sources—the difference of absorption coefficients and difference of phase shifts along and transverse to the direction of the magnetic field. The emergent wave is strongly polarized indicating that the effect of the differential absorption predominates. Although the rotation per wavelength is quite large even at small magnetic fields, the rotation possible is limited by certain saturation effects.

[1] E. Carr and R. D. Spence, Phys. Rev. **90**, 339A (1953).

C3. Nucleation of Ordered Phases in Cu_3Au. NORMAN W. LORD,* *Raytheon Manufacturing Company.*—Experimental data[1] covering the kinetics of ordering in Cu_3Au from 279 to 384°C is interpreted in accordance with nucleation theory. The ordering has been shown to proceed in two distinct stages. One can then associate different nucleation processes for each of them. The mechanism hypothesized for the complicated "coalescence" stage is consistent with available experimental evidence.[2] The earlier simple ordering stage has no observed incubation period and is assumed to follow the Becker theory. The second stage has an observed incubation period and only after this does it conform to the theory. The temperature dependence of the relaxation times for each stage are used to calculate the activation energy for the formation of growing nuclei. A value of 1.40 ev is used for the diffusion activation energy. The results are in qualitative agreement with Becker's sample theoretical calculations. The activation energy for the "coalescence" stage falls off much more rapidly with decreasing temperature than that for the first stage.

* The experimental work was done at Columbia University.
[1] N. W. Lord, Bull. Am. Phys. Soc. **28**, No. 2, 23 (1953).
[2] Jones and Sykes, Proc. Roy. Soc. (London) **166**, 376 (1938); Owen and Sim, Phil. Mag. **38**, 342 (1937).

C4. The Measurement of the Specific Heats of the Alkali Metals. H. PRESTON-THOMAS, T. M. DAUPHINEE, AND D. K. C. MACDONALD, *National Research Council, Canada.*—An apparatus of novel design has been constructed to measure the specific heats of some pure and alloyed alkali metals in the range from 15°K to 300°K; in particular Rb and Cs have never been measured. The range will later be extended to lower temperatures. We wished to reduce experimental errors to the order of 0.1 percent for the measurement of small anomalies and possible time-dependent effects; economy in the use of the scarcer metals was also important. These aims led to the following design: Eight cm^3 or less of the metal to be measured are cast in vacuum into the copper calorimeter and then sealed in under pure helium gas. Heat input is continuous during an experiment, the copper heating coil serving also as the thermometer. Adiabatic conditions are maintained and recorded automatically, manual adjustments being required only at intervals of several hours. All requisite data (power input, temperature, and time) appear on a single recorder chart, allowing for extraction or verification of results at any subsequent time. Measurements already completed on sodium show that the desired consistency has been achieved, while a series of test procedures suggests that systematic errors have been kept within the required limits.

C5. Thermoelectricity in Metals at Low Temperatures. D. K. C. MACDONALD AND W. B. PEARSON, *National Research Council, Canada.*—A wide range of experiments has been carried out to determine the absolute thermoelectric power down to ~4°K on the alkali and group IB metals both in the pure state and as dilute alloys. In all cases the temperature range extends at least to 70°K and in some cases to 300°K. Since these metals, and sodium and potassium in particular, are generally accepted to be good approximations to the theoretical model of an "ideal" metal, the data are particularly suitable for comparison with the modern theories of electron transport. Serious disagreement is found in both magnitude and temperature dependence, and it appears quite probable that the theory may be lacking in a number of respects. However, apart from the adequacy or otherwise of the fundamental theory, the results on the dilute alloys in particular appear to offer much useful information on both the "normal" and "abnormal" scattering of electrons in metals.

C6. An H-T Antiferromagnetic Boundary and Apparent Molecular Field for $MnBr_2 \cdot 4H_2O$. WARREN E. HENRY, *Naval Research Laboratory.*—The magnetization of manganous bromide tetrahydrate has been carried out at liquid helium temperatures and in magnetic fields up to 58 000 gauss. The general technique of measurement and analysis of data is the same as in previous work[1] with manganous chloride tetrahydrate. Thus one is enabled to make the following comparison:

	Néel temperature	Molecular field
$MnCl_2 \cdot 4H_2O$	~1.73°K	~14 000 gauss
$MnBr_2 \cdot 4H_2O$	~2.2 °K	~17 500 gauss

The Néel temperature is defined as the antiferromagnetic transition temperature in zero magnetic field. The field de-

pendence of the antiferromagnetic transition temperature was studied by carrying out moment measurements in a controlled, changing temperature and at fixed, constant magnetic fields. The critical temperature is reached when

$$(\partial M/\partial T)_H = 0.$$

Some values of $T_c(H)$ were thus obtained. By assuming that for $H > H_m$ no spontaneous antiferromagnetic ordering takes place at the absolute zero, one can set the limiting critical field equal to the molecular field. With these values of H_c and T_c, one can draw a curve and extrapolate to $H_c = 0$ to get the Néel temperature. Thus one obtains for $MnBr_2 \cdot 4H_2O$ an antiferromagnetic transition curve plotted in the H-T plane.

[1] W. E. Henry, Bull. Am. Phys. Soc. **28**, No. 3, 11 (1953); Phys. Rev. (to be published).

C7. Magnetostriction of Magnetite.* J. L. STULL AND L. R. BICKFORD, JR., *Alfred University.*—Magnetostriction measurements were made on circular wafers cut from natural and synthetic crystals and a synthetic polycrystalline specimen of Fe_3O_4. The strain gauge technique was used, with the data in the form of recorded curves of strain *vs* magnetic field. For measurements below room temperature (to 120°K) the strain gauges were calibrated by comparing results obtained for the thermal expansion of brass *vs* fused silica as measured by (1) strain gauges and (2) standard dilatometric techniques. At room temperature the magnetostriction is positive along [111] and [110], but negative along [100]. The magnetostriction is largest in magnitude along the body diagonal: $\lambda_{111} = 80 \times 10^{-6}$ for a synthetic crystal. In the temperature region in which the preferred direction of the spontaneous magnetization switches from [111] to [100] (*ca* 130°K) the structure of all the magnetostriction curves changes. In some cases λ_{100} changes sign. These results are correlated with other magnetic properties.

* Supported in part by the U. S. Office of Naval Research.

C8. Magnetic Resonance in Ferrimagnetic and Antiferromagnetic Systems.* L. R. BICKFORD, JR., *Alfred University.*—The previously reported[1] microwave resonance absorption spectrum of Fe_3O_4 at 83°K has been re-analyzed, and the observed doubling of resonance peaks has been attributed to the separate contributions of the A and B spins (spins of magnetic ions on the tetrahedral A sites and octahedral B sites, respectively). Some implications of the analysis are (1) the exchange field H_E need not appear in the resonance equations;[2] (2) resonance peaks in cubic ferrite materials are unresolved doublets, with the line width and apparent g factor being partially dependent upon the magnitude of magnetic anisotropy; (3) the disappearance of resonance absorption at the Curie temperature of antiferromagnetics is a magnetic anisotropy effect; and (4) the Fe_3O_4 transition appears to be primarily a magnetic transition of a type which might be expected to occur in certain other ferrites and in antiferromagnetic materials.

* Supported in part by the U. S. Office of Naval Research.
[1] L. R. Bickford, Jr., Phys. Rev. **78**, 449 (1950).
[2] C. Kittel, Phys. Rev. **82**, 565 (1951).

C9. Phase Transitions in the $NaNbO_3$-$KNbO_3$ System.* G. SHIRANE,† R. E. NEWNHAM, AND R. PEPINSKY, *The Pennsylvania State College.*—Phase transitions in $KNbO_3$ and $NaNbO_3$ have been examined by dielectric[1] and x-ray[2] measurements. The transitions in $KNbO_3$ are rather similar to those in $BaTiO_3$, the crystal being ferroelectric below 435°C. Though $NaNbO_3$ was also reported as ferroelectric,[1] Vousden[3] reported a nonpolar space-group for this crystal. Dielectric, optical, x-ray, and specific heat measurements have been carried out, in an exploration of the phase diagram of the $NaNbO_3$-$KNbO_3$ system, using both single crystal and ceramic specimens. No evidence for ferroelectricity is obtained for pure $NaNbO_3$ by dielectric and pyroelectric tests, but a ferroelectric phase appears upon addition of a small amount of $KNbO_3$. Dielectric properties and their relations to crystal structure are reported for the complete $NaNbO_3$-$KNbO_3$ system.

* Development supported by the Air Research and Development Command and the U. S. Office of Naval Research.
† On leave from Tokyo Institute of Technology, Tokyo, Japan.
[1] B. Matthias and J. Remeika, Phys. Rev. **82**, 727 (1951).
[2] E. A. Wood, Acta Cryst. **4**, 353 (1951).
[3] P. Vousden, Acta Cryst. **4**, 545 (1951).

C10. Study of the Transition in $LiNH_4C_4H_4O_6 \cdot H_2O$.* F. JONA AND R. PEPINSKY, *The Pennsylvania State College.*—Lithium ammonium tartrate monohydrate has been reported to be ferroelectric in the direction of the b axis below about 100°K.[1, 2] The behavior of the dielectric constant ϵ_b has been re-examined in the range from −190° to about +120°C and appears to be quite different from the behavior in other ferroelectric crystals. A Curie-Weiss law can be assumed only in a small temperature range above the Curie point. Another interpretation of this behavior is given. The dielectric constant ϵ_a shows a small anomaly at the Curie point, whereas ϵ_c is essentially independent of temperature. The dependence of the three dielectric constants on a dc biasing field has been investigated as a function of the temperature, and thermal expansion has been examined by dilatometric measurements. The effect of a partial substitution of hydrogen by deuterium on the dielectric properties has also been investigated.

* Development supported by Air Research and Development Command.
[1] B. T. Matthias and J. K. Hulm, Phys. Rev. **82**, 108 (1951).
[2] W. J. Merz, Phys. Rev. **82**, 562 (1951).

THURSDAY AFTERNOON AT 2:00

Biology Lecture Room

(L. P. SMITH presiding)

Solid State Physics, II

D1. Color Center Formation in Alkali Halides Containing $S^=$. E. BURSTEIN AND B. W. HENVIS, *Naval Research Laboratory.*—The addition of $S^=$ to KCl and KBr enhances the formation of the F band and suppresses the formation of other trapped electron bands such as the R, M, and N bands. Since negative ion vacancies are introduced simultaneously with the divalent anions in order to maintain neutrality, the increased darkenability of alkali halide crystals containing $S^=$ is attributed to an increased concentration of negative ion vacancies and possibly to an increased trapping

of holes, presumably by $S^=$. The crystals also exhibit a marked increase in the bleachability of the F band which may be attributed to the absence of "hard F centers" and to the trapping of holes by $S^=$ to form centers, with bands in the ultraviolet, which allow ready recombination of the trapped holes with electrons. The presence of $S^=$ extends the ultraviolet absorption edge of KCl to about 2200A and that of KBr to about 2300A.

D2. Time-Dependent Spectra of Electroluminescent Zinc Sulfide. E. E. LOEBNER, *Sylvania Electric Products Inc.*—The brightness during electroluminescence has been investigated heretofore as a function of either time or wavelength only.[1] An AO Rapid Scanning Spectrograph makes a simultaneous measurement possible. The data can be represented as a surface in three-dimensional, brightness-wavelength-time space. Sections parallel to the brightness-time plane intersect the surface in monochromatic "waves of brightness." They exhibit generally sharp asymmetrical peaks and shallow minima. A relative phase shift with wavelength is apparent. A projection into the brightness-wavelength plane results in two spectral envelops of all the minima and maxima of brightness. This permits a separation into a permanent and fluctuating component of radiation. The former is insensitive to variations in magnitude and frequency of the exciting electric field, while the latter exhibits a sharp rise at the blue end, shifting toward the violet, with increasing frequency. A fine structure of about ten bands between 4000A and 5800A is apparently associated with the Stark effect. These data furnish new insight into the mechanism of electroluminescence, which promises to become a powerful tool in solid state physics.

[1] Destriau, Phil. Mag. **38**, 700 (1947); Waymouth *et al.*, Sylvania Technologist **5**, 54 (1952).

D3. Interpretation of Some Electroluminescent Effects. FRANK MATOSSI, *U. S. Naval Ordnance Laboratory.*—The consideration of electron transitions between valence band, conduction band, and traps as presented by Randall and Wilkins' theory of luminescent growth is extended to include terms which take into account emptying of traps by an electric field, the change of transition probabilities, and the draining off of electrons into surface traps. The result of the mathematical analysis corresponds to effects observed in a sulfide phosphor under the influence of a periodic electric field while continuously excited by ultraviolet radiation. These are a momentary illumination, an extinguishing effect, and the superposition of a ripple with twice the frequency of the field, whose amplitude decreases with increasing frequency. The draining effect is acting only as long as not all surface states are filled. At low frequencies, polarization and current effects have to be taken into account. These will be discussed in general terms, together with relevant observations.

D4. Efficiency of Conversion from Light to Electric Power by a Ge Grown Junction. RALPH P. RUTH AND JAMES W. MOYER, *Knolls Atomic Power Laboratory.**—The efficiency with which a Ge grown junction converts power received from incident light into maximum power in an external resistive load has been measured as a function of incident radiation intensity. The crystal used was a disk cut from an ingot with the junction parallel to the faces and close to the n face; the light was incident normal to the surface on the n side. The observed efficiency for white light increases approximately as the $\frac{3}{4}$ power of the incident intensity over an intensity range of three decades before leveling off at a maximum for an intensity of 0.1 watt cm^{-2}. The maximum efficiency, uncorrected for the quantum efficiency of the process or for the reflectivity of the Ge, is approximately $\frac{1}{2}$ percent. For infrared radiation beyond 0.9μ the efficiencies were slightly higher. An effective quantum conversion efficiency appreciably less than 100 percent was observed with the junction used. If this effect were not present power conversion efficiencies several times as large as those observed might be attained. The theory of the photovoltaic effect at a p-n junction has been developed to the point of qualitative agreement with the observed efficiency-intensity relationship.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.

D5. Diffusion of Lithium into Germanium and Silicon. C. S. FULLER AND J. A. DITZENBERGER, *Bell Telephone Laboratories.*—The diffusivity of lithium in p type single crystals of Ge and Si has been investigated in the range 300 to 1000°C by the method previously described.[1] Lithium is found to be a donor in Ge and Si. The equations, $D=13\times10^{-4}\exp(-10700/RT)$ and $D=94\times10^{-4}\exp(-18100/RT)$, are found to apply to the diffusion of Li in Ge and Si, respectively, where D is the diffusivity in cm^2/sec and $R=1.98$ calories. Li shows a maximum solubility of approximately 10^{19} cm^{-3} in both Ge and Si, assuming each Li atom supplies one electron to the conduction band. This maximum occurs at 500±25°C for Si. However, because of spontaneous precipitation of Li at room temperature in Ge, the temperature dependence of solubility for Li in Ge is less certain.

[1] C. S. Fuller, Phys. Rev. **86**, 136 (1952).

(Abstract withdrawn)

D7. Etch Pits in Plastically Deformed Germanium. C. J. GALLAGHER, *General Electric Research Laboratory.*—Following plastic flow in germanium, etch pits, with separations of a few microns at small strains, have been observed in (111) faces, aligned on slip lines which are traces of (111) planes. These show certain similarities to those found by Vogel, Pfann, Corey, and Thomas,[1] which were interpreted as sites of single dislocations at small angle grain boundaries. Similar pits have also been observed in (111) faces in material subjected to thermal shock where there is no external evidence of slip. On other faces the slip lines disappear as the etch proceeds, with no pits developed. The incubation time for plastic flow[2] follows the relation suggested by Seitz[3] $\tau=\tau_0 e^{Q/RT}$ ($\tau_0=3\times10^{-5}$ second, $Q=24\,000$ cal/mole). Thermoelectric measurements on high resistivity germanium bent at temperatures below 500°C show that the deformed region is always more p type, probably due to the introduction of electron trapping states associated with lattice defects. Minor-

ity carrier lifetimes in the same material are less than a few microseconds.

[1] Vogel, Pfann, Corey, and Thomas, Bull. Am. Phys. Soc. **28**, No. 2, 32 (1953).
[2] C. J. Gallagher, Phys. Rev. **88**, 721 (1952).
[3] F. Seitz, Phys. Rev. **88**, 722 (1952).

D8. Floating Zone Recrystallization. P. H. Keck, W. Van Horn, J. Soled, and A. MacDonald, *Signal Corps Engineering Laboratories.*—Equipment to carry out recrystallization and zone melting of silicon from a floating liquid zone[1] will be described and results obtained are discussed.

[1] P. H. Keck and M. J. E. Golay, Phys. Rev. **89**, 1297 (1953).

D9. Crystal Growth of Silicon by the Tip Fusion Process. P. H. Keck, S. B. Levin, J. Broder, and R. Lieberman, *Signal Corps Engineering Laboratories.*—In this new method, which does not require a container for the melt, a seed crystal is supported on a pedestal in a gas tight chamber. The tip of the crystal is melted by radiation or induction heating and is maintained in the molten state while a stream of finely divided powder is slowly fed from above into the liquid tip. The growing crystal is lowered at such a rate that the molten zone remains of nearly constant size. The method is similar to the Verneuil process[1] in some respects but differs in others; in particular it is free from the limitations imposed by the use of a combustion flame. The tip fusion process can be carried out in vacuum or any desired gas atmosphere. It is very suitable for silicon and other high melting materials. Results obtained on silicon will be discussed.

[1] A. Verneuil, Compt. rend. **135**, 791 (1902).

D10. Crystal Habit of Silicon and Germanium. G. Wolff, *Signal Corps Engineering Laboratories.*—A study of natural faces has been undertaken on silicon and germanium grown from the melt, from the gaseous phase and from solutions. The experimental results are compared with the theoretical expectations.

Invited Paper

D11. A New Method of Calculating Energy Bands in Crystal Lattices. Walter Kohn, *Carnegie Institute of Technology.* (40 min.)

Thursday Afternoon at 2:00
Lower Strong Auditorium
(Daniel Alpert presiding)

Electron Physics

E1. Electron Ejection from Metals by Positive Ions and Metastable Atoms of a Few Electron Volts. David Sternberg, *Columbia University.* (30 min.)

E2. Theory and Experiment Concerning Resonance Transitions and Auger Transitions Occurring as an Ion Approaches a Metal Surface. H. D. Hagstrum, *Bell Telephone Laboratories.* (30 min.)

Contributed Papers

E3. Electron Emission from Metals Under High Energy Positive Ion Bombardment. Henry C. Bourne, Jr., Robert W. Cloud, and John G. Trump, *M.I.T.*—Measurements were made of the electron yield from targets of aluminum, steel, magnesium, copper, gold, and lead when bombarded by ions from hydrogen, helium, nitrogen, xenon, and mercury. The ions, whose energy was varied over the range from 10 to 140 kilovolts, were produced by ionization of the residual gas in the anode electrode and emerged through a small opening into the essentially uniform accelerating field. A rapid initial rise of electro emission with ion energy was followed in all cases by a slow linear increase. The emission ratio varied from 2 to 20 and was maximum for nitrogen ions on steel. The dependence on extractive gradient at the bombarded metal surface was slight and no simple dependence on the nature of the ion or of the bombarded metal was observed. The significance of these measurements on a theory of high voltage breakdown in vacuum will be discussed.

E4. Vacuum Fluctuation Noise in Electron Streams.* J. Weber, *University of Maryland.*—For a slightly damped oscillator, the mean squared noise voltage is given by[1]

$$\overline{V^2}=\frac{1}{C}\left[\frac{h\nu}{2}+\frac{h\nu}{\exp(h\nu/kt)-1}\right],$$

where C is the capacity. The first term represents the effect of the vacuum fluctuations and the second term represents the effect of the thermal fluctuations. This value is predicted to be the result of precise measurements of the mean squared electromotive force. It is well known that the use of electrons[2] as test charges does not in general lead to precise field measurements. Nonetheless a perturbation theory calculation shows that the noise induced in a small current electron stream which interacts weakly with a damped oscillator corresponds precisely to the value which would be calculated classically using the expression above. The transit angle was assumed to be small. Both the thermal and the vacuum fluctuations contribute to the electron stream noise.

* Supported by the U. S. Office of Naval Research.
[1] J. Weber, Phys. Rev. **90**, 977 (1953).
[2] W. Heitler, *The Quantum Theory of Radiation*, p. 78.

E5. Electrical Breakdown of Extremely Short Gaps. P. Kisliuk, *Bell Telephone Laboratories.*—Breakdown across short gaps (~1000A) has been shown to take place at voltages far below the minimum sparking potential. Arc voltages show that the discharge is in metal vapor,[1] and pressures of several atmospheres are developed. Breakdown fields are on the order of 3×10^6 volts/cm. The initiation time of these arcs is at most 3×10^{-9} seconds,[2] and each ion must produce many electrons. The number of electrons liberated by an ion approaching the cathode surface[3] is insufficient, so the field at the cathode must remain high enough to maintain the current by field emission. Ions are necessary to prevent space charge limitation of the current. Only 0.3 percent of the current at the cathode is carried by ions, so that heat and material transfer measurements can be explained in terms of the energy dissipated at the anode by electron impact, and the evaporation and condensation of metal on the electrode sur-

faces. Possible origins of the initiating ions when the initial $p\ d$ product is very low will be discussed.

[1] L. H. Germer and F. E. Haworth, J. Appl. Phys. **20**, 1085 (1949).
[2] L. H. Germer and J. L. Smith, J. Appl. Phys. **23**, 553 (1951).
[3] R. R. Newton, Phys. Rev. **73**, 1122 (1948).

E6. Probe Measurements in an Argon Discharge Containing Running Striations.* N. L. OLESON, *U. S. Naval Postgraduate School.*—A direct current discharge containing argon is known to have oscillations in tube voltage, current and light intensity.[1] In the present investigation a small cylindrical tungsten probe is inserted into the positive column of an argon discharge and held at a fixed potential with respect to the anode. The region adjacent to the probe is scanned by a photomultiplier (RCA, 931A). The voltage developed across a small resistance in series with the probe is fed through a preamplifier to one beam of a Du Mont 279 Oscilloscope, the output of the phototube to the other beam. This permits a study of probe current *versus* light intensity. Preliminary measurements with an argon discharge reveal a sharp burst of electrons prior to maximum light intensity and a maximum positive ion current near the maximum light intensity. A movable probe discharge tube has also been constructed and will be described.

* This work is supported by the U. S. Office of Naval Research.
[1] T. Donahue and G. H. Dieke, Phys. Rev. **81**, 248 (1951).

THURSDAY AFTERNOON AT 2:00

Upper Strong Auditorium

(J. S. FOSTER presiding)

Nuclear Masses; Radioactive Substances

F1. Some Mass-Spectrographic Studies of Nuclear Stability. H. E. DUCKWORTH, *McMaster University.* (30 min.)

Contributed Papers

F2. Atomic Masses for Ga, Ge, As, Se, and Br.* B. G. HOGG† AND H. E. DUCKWORTH, *McMaster University.*—New mass spectrographic measurements are combined with existing transmutation and microwave absorption data to give the following masses: Ga^{69}=68.9478±2 amu, Ge^{70}=69.9460±4 amu, Ge^{72}=71.9449±2 amu, Ge^{74}=73.9447±4 amu, Ge^{76}=75.9460±4 amu, As^{75}=74.9454±3 amu, Se^{74}=73.9460±4 amu, Se^{76}=75.9432±2 amu, Se^{77}=76.9442±2 amu, Se^{78}=77.9420±2 amu, Se^{80}=79.9421±6 amu, Se^{82}=81.9431±6 amu, Br^{79}=78.9435±4 amu, and Br^{81}=80.9425±5 amu. These constitute all the stable isotopes of these elements with the exception of Ga^{71} and Ge^{73}.

* Work supported by the Research and Development Command, U. S. Air Force, the National Research Council of Canada, and the Research Council of Ontario.
† National Research Council of Canada Fellow.

F3. Applications of the Wigner Semi-Empirical Mass Formula to Isobars.* J. T. MCCARTHY, *Western Reserve University.*—The success of most applications of semi-empirical mass formulas has been limited because of attempts to apply the formulas over wide regions of the periodic table. Discontinuities in binding energy arise near magic-number nuclei; these appear to indicate the formation of closed shells of protons and neutrons. In two recent publications[1] the Wigner formula has been shown to be fairly successful in regions where there are no discontinuities. In the present work the empirical parameter of this formula has been evaluated, by means of mass-spectrographic and distintegration-energy data, for several regions above A=36. In regions free from discontinuities the parameter appears to be a smooth function of A with few exceptions. Using these values of the parameter the energy available for double-beta decay between many isobars has been calculated. The limitations and degree of reliability of the formula will be discussed.

* Supported by the National Science Foundation.
[1] Collins, Nier, and Johnson, Phys. Rev. **86**, 408 (1952); R. E. Halsted, Phys. Rev. **88**, 666 (1952).

F4. K Capture in Na^{22}.* R. H. MILLER AND R. SHERR, *Princeton University.*—We have investigated the decay of Na^{22} using a $4\pi\beta$ proportional counter to detect the positrons and a NaI(Tl) scintillation counter for the γ-rays. Setting the two counters in coincidence the ratio of coincidences to γ-counts is equal to $\epsilon_\beta[\eta_1+(1-K)\eta_2]$, where ϵ_β is the β-counter efficiency; η_1 and η_2 are the fractions of the total γ-counts due to annihilation radiation and 1.28-Mev γ-rays, respectively, for a given setting of the bias of an integral discriminator which selects the γ-pulses for the coincidences; K is the percentage K capture. By varying the bias we obtain data which fit this expression fairly well, leading to a value for K of 9±2 percent and $\epsilon_\beta \approx 0.98$. Little change was observed for foils of zapon and aluminum covering the (massless) source up to 170 $\mu g/cm^2$. (Correction for the fluorescent yield of Na^{22} will increase K by a small amount.) The value of K calculated for an allowed transition (Feenberg and Trigg) is 10 percent (corrected for shielding).

* This work was supported in part by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

F5. Radiations from As^{77} and Ge^{77}.* B. L. SARAF, J. VARMA, AND C. E. MANDEVILLE, *Bartol Research Foundation.*—As^{77} was grown from its germanium parent when GeO_2 was irradiated by slow neutrons in the Oak Ridge pile. Gamma-rays decaying with the 40-hr period were detected at 85 kev, 160 kev, 250 kev, 270 kev, and 520 kev, the relative intensities of the unconverted quantum radiations being 3, 1, 20, 0.04, and 6. Gamma-rays of lower energies may also be present. The continuous nuclear gamma-ray spectrum accompanying orbital electron capture in the 11-day Ge^{77} has an end point at 225±12 kev, yielding a value of 4.3 for log ft of the allowed electron capture transition which may be designated as $p_{1/2} \rightarrow p_{3/2}$, in agreement with the assignment of a spin of $\frac{1}{2}$ to Ge^{77} in accord with the shell model.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

F6. Radioactivity of Sm^{153}. ROBERT KATZ AND MILFORD R. LEE, *Kansas State College.*—The radiations from 47.0-hr Sm^{153} have been studied in a variable-field, 180° focusing, beta-ray spectrometer-spectrograph. Three beta-ray spectra

of maximum energy and relative intensity 0.255-Mev, 9 percent; 0.685-Mev, 70 percent; 0.795-Mev, 21 percent have been found, and a fourth of maximum energy 0.62-Mev and relative intensity <2 percent has been postulated. Conversion electrons have been found of gamma-rays of energy 0.0691, 0.1027, and 0.548-Mev. A decay scheme in excellent agreement with nuclear shell theory is proposed in which spin and parity have been assigned to all levels. The discrepancy between the magnetic moment measurement and shell theory with regard to the ground state of Eu^{152} has been resolved in favor of the $d_{5/2}$ assignment of shell theory. No excited $h_{11/2}$ state has been found in Eu^{152}. This, together with the scarcity of odd proton isomers in the region $Z=50$ to 82 as compared to the relative abundance of odd neutron isomers in the same region,[1] may imply that the pairing energy for protons of high j is greater than that for neutrons.

[1] M. Goldhaber and R. D. Hill, Revs. Modern Phys. **24**, 179 (1952).

F7. Radioactivities of Thallium Isotopes.* INGMAR BERGSTRÖM AND R. D. HILL, *University of Illinois.*—A large number of the Tl activities can be produced from (d,n) and $(d,2n)$ reactions using ordinary Hg. Mercury has six stable isotopes with abundances ~10 per cent between $A=198$ and 204. It is therefore possible to produce every Tl isotope between 198 and 205 with 10-Mev deuterons. We have studied the K capture activities of Tl using beta-ray spectrographs which cover the electron energy region from about 15 kev to 800 kev. Thus far we have observed about 150 conversion (not γ-ray) lines, decaying with the lifetimes between 2 hours and 12 days. One isomeric transition of 260 kev (approximately 2 hours half-life) and of $M4$ character has been observed. This transition may be the 1.8 hr Tl^{196} activity already observed but further work is in progress to establish its mass number. The isomeric γ-ray is followed by a 282-kev γ-ray, probably due to a magnetic dipole transition. The ground state of Tl^{198} has been observed to decay with a half-life of about 4 hours. This has been shown by following the decay of the well-known 411-kev and 695-kev transitions of Hg^{198}. Many of the other γ-rays can be fitted into some of the already known level schemes of Hg.

* Assisted by joint program of the Atomic Energy Commission and the U. S. Office of Naval Research.

F8. Alpha-Gamma Angular Correlation in Ionium (Th^{230}). G. M. TEMMER AND J. M. WYCKOFF, *National Bureau of Standards.*—We have studied the angular correlation between the alpha-particles of Th^{230} leading to the first excited state of Ra^{226} and the subsequent 68-kev gamma-ray to the ground state. Rosenblum *et al.* have classified the latter as an $E2$ transition by comparison of L shell conversion measurements with theoretical calculations.[1] We measured coincidences of alpha-particles in a 0.001-inch terphenyl flake with gamma-pulses from a thin NaI(Tl) crystal.[2] The angle subtended by both detectors was ten degrees. Accidental coincidences accounted for at most five percent of the total coincidence rate. The angles between counters, the corresponding counting rates (counts/hour) and standard deviations follow (uncorrected except for accidentals): 84°, 4.65±0.71; 135°, 9.38±0.91; 180°, 3.53±0.60; 225°, 9.74±1.10. The correlation function which comes closest to these results is $\sin^2 2\theta$, corresponding to a 0-2-0 transition. This establishes another case of $J=2^+$ for the first excited state of an even-even nucleus.[3] The experiment is being refined to determine any slight deviations from the pure $\sin^2 2\theta$ correlation.[4]

[1] S. Rosenblum and M. Valadares, Compt. rend. **234**, 2359 (1952); Gellman, Griffith, and Stanley, Phys. Rev. **85**, 944 (1952).
[2] We are indebted to Dr. Paul Fields of the Argonne National Laboratory for supplying the electromagnetically separated source.
[3] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
[4] A. Abraham and R. V. Pound, Phys. Rev. **89**, 1306 (1953).

F9. Indications of the Interaction of Electric Field Gradients and Nuclear Electric Quadrupole Moments in Angular Correlation. ROLF M. STEFFEN,* *Purdue University.*—It is well known that the Cd^{111} γ-directional correlation depends strongly on the chemical state and on the environment of the decaying In^{111} atom. This was explained hitherto by magnetic interaction. However, magnetic decoupling experiments with a magnetic field applied in the direction of the propagation of one γ-ray showed no tendency to restore the maximum directional correlation.[1, 2] This result seems to indicate that the attenuation of the Cd^{111} correlation in solid sources is due to the interaction between the crystalline grad E field and the electric quadrupole moment of the 0.247-Mev excited state of Cd^{111}. The largest anisotropy found for nonmetallic solids is exhibited by In_2O_3 and $In(OH)_3$. Both are cubic crystals with relatively small values of grad E at the position of the In, owing to the high symmetry of their space groups: T_h^7 and T_h^3, respectively. A further indication that the attenuation of the Cd^{111} correlation in the solid sources is caused by crystalline grad E field stems from the fact that, without exception, liquid In^{111} sources of very different character give the maximum correlation. During the progress of this work a convincing proof for the electric quadrupole interaction on the Cd^{111} correlation has been given by the results obtained with single crystals of Indium as sources.[1]

* Supported in part by the U. S. Atomic Energy Commission.
[1] Albers, Schonberg, Hanni, Heer, Novey, and Scherrer, Phys. Rev. **90**, 322 (1953).
[2] R. M. Steffen, Phys. Rev. **90**, 321 (1953).

FRIDAY MORNING AT 10:00

Lower Strong Auditorium

(L. W. PHILLIPS presiding)

Cryogenics

G1. The Hydrodynamics of Liquid Helium II. K. R. ATKINS, *University of Toronto.* (30 min.)

Contributed Papers

G2. A Theory of Liquid Helium. JOHN M. RICHARDSON, *Bureau of Mines.*—Our model is a system of identical bosons of spin O interacting with central forces within a container of volume V. We first define an effective Hamiltonian $\bar{H}$ dependent only upon the occupation numbers of the momentum states. $\bar{H}$ is defined so that the sum of $\exp[(\mu N-\bar{H})/kT]$ over occupation numbers is equal to the correct grand partition function for the above model. We set up the correspond-

ing variational problem of pressure maximization, and in it we approximate the distribution function by a product of factors each referring to the occupancy of a momentum state. In $\mathcal{H}$ we neglect terms cubic and higher order in the occupation numbers. It is possible to express the variational problem in terms of the average occupation numbers. We assume that states of nonvanishing momentum are normally occupied, that is, their average occupation numbers are independent of the volume V. However, we admit the possibility that the state of vanishing momentum may be abnormally occupied, that is, the average occupation number may be proportional to the volume. When this possibility is favored by the variational principle, we interpret it to be the superfluid component. The quasi-continuum of normally occupied states constitutes the normal component. The results will be discussed in detail.

G3. On the Theory of Liquid He_3–He_4 Mixtures. LOUIS GOLDSTEIN, *Los Alamos Scientific Laboratory.*—The asymptotic model of Liquid He_3–He_4 mixtures has been investigated whereby the components are represented as ideal antisymmetric and symmetric fluids, respectively, whose atoms are constrained to move in a smoothed constant potential energy well. Complete miscibility is indicated at all temperatures. The isothermal energy of mixing is positive at low temperatures provided that the degeneracy of the antisymmetric component be small. The phase transition exhibited by the symmetric component is perturbed. While it is a smooth first-order phase change in absence of He_3, it becomes a third-order one in the presence of the latter. The constant pressure and volume heat capacities of the mixtures have sharp peaks along the transition line; their temperature derivatives have lambda-points along this line. The transition line is thus associated with a well-defined third-order phase change with the exception of its two limiting points. The one with vanishing He_3 concentration corresponds to a first-order phase change, while the other, with vanishing He_4 concentration, is not associated with any transition of finite order.

Optical Physics

G4. Recent Developments in the Infrared Spectroscopy of Gases at Very High Pressures. H. L. WELSH, *University of Toronto.* (30 min.)

Contributed Papers

G5. Intensity of Lyman-Alpha Line in Solar Spectrum.* WM. A. RENSE, *University of Colorado.*—Analysis of the Lyman-alpha emission line in the solar spectrum, recently photographed with a grazing-incidence concave grating spectrograph flown in an Aerobee rocket December 12, 1952, has been completed. The exposure was made at an average height of 81 km. From instrument constant an estimate of line intensity and line profile was made. The wavelength was computed to be 1215.5±1A. The line exhibits, at the altitude range of the rocket during the 28-second exposure, a narrow emission center with broad emission wings. The width is about 5A, but instrumental scattering may have masked the possible extension of the line into a faint continuum. The total intensity of the Lyman-alpha radiation at the earth, after atmospheric absorption is allowed for, is estimated to be 0.05 microwatts/cm^2. Solar activity was well above average on the day of the flight, and there are indications that Lyman-alpha intensity was correspondingly high at the time of the flight.

* The research reported in this paper has been sponsored by the Geophysics Research Directorate of the Air Force Cambridge Research and Development Center.

G6. Theory of Fine Structure Pressure Broadening of Spectral Lines.* MAKOTO TAKEO AND SHANG-YI CH'EN, *University of Oregon.*—The existence of the difference in behavior of the shift and the broadening of the absorption series lines of alkali atoms under different pressures of foreign gases has been well-established experimentally.[1] Presumably because of the lack of knowledge of intermolecular interaction, this fact is not yet accounted for theoretically. Assuming the limit of statistical approach, an extended picture of Thomas-Fermi atomic model to include optically excited states under hydrostatic pressure is proposed. Result shows a new force law involved for excited states in addition to Lennard-Jones' repulsion force under spherically symmetric assumption. Perturbation and variation method are applied to the Michels, de Boer, and Bijl's model[2] of compressed atom by expanding the infinite potential wall in terms of Dirac's δ-function to have an atomic wave function perturbed by pressure. Then the doublet separation is calculated to show linear dependence on relative density of nonpolarizable foreign gases. Differences of van der Waals' forces for $^3P_{3/2}$ and $^3P_{1/2}$ states will be attributed to the difference in charge distribution between them. An atom at $^3P_{1/2}$ state is spherically symmetric, while one at $^3P_{3/2}$ state has electric quadrupole moment. The fact will be discussed that the difference is never small in the fine structure pressure broadening.

* This work is supported by a research grant of the National Science Foundation.

[1] S. Y. Ch'en and D. A. Kohler, Phys. Rev. (to be published).

[2] Michels, de Boer, and Bijl, Physica **9**, 981 (1937).

G7. The Recording of X-Ray Diffraction Patterns by a Scintillation Counter. J. C. M. BRENTANO AND I. LADANY, *Northwestern University.*—Counter techniques present the advantage over photographic recording that count rates are proportionate to intensities. The G-M counter generally used is, however, unfavorable for evaluating intensity distributions by sectional scanning because of the limited yield for x-ray photons and the count loss for high count rates. Either regions of low count rate are affected by statistical fluctuations or those of high count rate by systematic errors difficult to assess. Thalliated sodium iodide scintillation counters present high absorption and permit high counting rates. An effective way of reducing the background count was found in limiting the crystal size to the beam cross section. We could thus reduce the background to 0.3 count/sec. With molybdenum K α-radiation the photons are easily countable. Using a nuclear 162 unit with discriminator, proportionality between intensity and count rate was observed up to 36 000 counts/sec. Under comparative conditions count rates were over one order of magnitude higher than for G-M counters for cobalt radiation and sufficiently high to permit scanning with a powder rod. Apart from higher accuracy of scintillation counting use of molybdenum radiation permits simple instrumentation and suppresses differential absorption of mixed powders.

FRIDAY MORNING AT 9:30

Upper Strong Auditorium

(L. APKER presiding)

I1. The Darkening of Crystals of the Silver Halides by Light. F. SEITZ, *University of Illinois.* (40 min.)

I2. The Present Status of the Electronic Properties of Silver Chloride. L. P. SMITH, *Cornell University.* (40 min.)

I3. Low-Intensity Reciprocity Law Failure in Photographic Exposure and Its Dependence on a Two-Quantum Process. JULIAN WEBB, *Eastman Kodak Company.* (25 min.)

I4. Some Fundamental Approaches to the Problems of Photographic Sensitivity. FRANZ URBACH, *Eastman Kodak Company.* (25 min.)

FRIDAY MORNING AT 10:00

Biology Lecture Room

(G. SCHARFF-GOLDHABER presiding)

Interactions of High-Energy Protons; Nuclear Energy Levels

J1. Interactions of 2.2-Bev Protons in Nuclear Emulsions. L. W. SMITH, C. P. LEAVITT, A. M. SHAPIRO, C. E. SWARTZ, AND M. WIDGOFF, *Brookhaven National Laboratory.**—Four-hundred micron Ilford G-5 emulsions have been exposed in the monoenergetic internal proton beam at the Brookhaven Cosmotron. Convenient exposures of $\sim 3\times 10^4$ protons per cm^2 are obtained in one pulse by accelerating a fraction of the injector Van de Graff dc beam. Background is minimized by using a pneumatic plunger to propel the emulsions from behind the shadow of the back wall into the vacuum chamber and a few milliseconds later turning off the rf accelerating voltage allowing the beam to spiral in upon the plates. The proton energy is determined by a knowledge of the beam radius and rotation frequency or field value. The spread in projected and dip angles of the beam in the emulsion is a few tenths of a degree, and the protons on the average traverse several centimeters of emulsion. "Along the track" scanning of approximately ten meters of track yields a total interaction mean free path of 33 ± 6 cm (approximately 0.8 geometrical cross section) in agreement with area scanning and flux measurements. Approximately thirty percent of the total events are apparent scatterings consisting of a single outgoing minimum track with or without a short ($<10\mu$) recoil. Characteristics of the interactions will be discussed.

* Under the auspices of the U. S. Atomic Energy Commission.

J2. Stars Induced in Nuclear Emulsions by 2.2-Bev Protons. M. WIDGOFF, C. P. LEAVITT, A. M. SHAPIRO, L. W. SMITH, AND C. E. SWARTZ, *Brookhaven National Laboratory.** Ilford G-5 plates exposed in the 2.2-Bev proton beam inside the Cosmotron have been examined for stars. Only stars which have an incoming minimum track within $\pm 1°$ of beam direction have been considered. These stars constitute 85–90 percent of all stars found by area scanning. The star size distribution has been obtained for about 300 of these proton stars:

Number of outgoing tracks	3–6	7–10	11–14	15–18	>18.
Number of stars	103	82	68	35	6.

For 130 of these stars the outgoing tracks have been classified with regard to their ionization, and the angular distributions of the light ($<1.2\ g_{min}$) and gray (1.2–$3\ g_{min}$) tracks have been found. Fifty-five percent of these stars have at least one light outgoing track, and 77 percent have at least one gray outgoing track, the mean outgoing track numbers being 0.7 light, 1.3 gray, and 7.6 black. The angular distributions show marked forward peaks: for light tracks the forward to backward ratio is 16:1, for gray tracks 10:1. These results are preliminary, and further work on the analysis of these interactions is in progress.

* Under the auspices of the U. S. Atomic Energy Commission.

J3. Determination of Level Parameters for Low Energy Neutron Resonances. J. S. LEVIN, D. J. HUGHES, AND W. Y. KATO, *Brookhaven National Laboratory.**—Methods have been developed for obtaining σ_0 and Γ separately for neutron resonances below about 10 ev where the instrumental resolution is of the same order as the width of the resonance (broadened by the Doppler effect). In those cases where the resolution is somewhat greater than the level width a method involving the measurement of the areas above transmission dips of thick and thin samples can be used.[1] Where the resolution width is smaller than that of the resonance level methods have been worked out for correcting measured thin sample transmission curves for the effect of instrumental resolution. With a resolution of 0.09 ev full width at half-maximum, preliminary measurements using the area method give $\sigma_0=32\,000$ barns (isotopic), $\Gamma=0.14$ ev for the 5 ev resonance in Ag. For the same resonance the method of correcting the transmission dip for the resolution function gives $\sigma_0=29\,000$ barns, $\Gamma=0.20$ ev. These measurements will be discussed and results for other low energy resonances will be presented.

* Under auspices of the U. S. Atomic Energy Commission.

[1] Melkonian, Havens, and Rainwater, Bull. Am. Phys. Soc. **28**, No. 3, 26 (1953).

J4. Energy Levels in Thorium. D. J. HUGHES, W. Y. KATO, AND J. S. LEVIN, *Brookhaven National Laboratory.**—The nuclear energy levels in Th at excitation energy just above neutron binding have been measured by observation of neutron resonances with the Brookhaven fast chopper. This zero-spin nucleus constitutes a useful comparison with Ag, whose level density has already been measured.[1] In the neutron energy region 0–100 ev, where all resonances are re-

solved, the observed spacing is 25 ev, actually somewhat less than the value for Ag (44 ev). This spacing of levels of a single J value is about ten times larger than predicted by the usual statistical model, although this model is in good agreement with 1-Mev neutron cross sections for heavy elements. The neutron widths may be calculated if Γ_λ is assumed to be 0.1 ev; the reduced (to 1 ev) widths obtained about 0.3 mv are much narrower than the value (3 mv) expected from the observed spacing. There is one wide level at 70 ev, however, of unreduced width 30 mv, for which the large scattering is evidenced by the characteristic interference dip.

* Under auspices of the U. S. Atomic Energy Commission.
[1] Kato, Stafne, Levin, and Hughes, Bull. Am. Phys. Soc. **28**, No. 3, 26 (1953).

J5. Preliminary Results with the Indiana Heavy Particle Spectrometer.* V. K. RASMUSSEN, D. W. MILLER, B. M. CARMICHAEL, AND M. B. SAMPSON, *Indiana University.*—A point-focusing magnetic spectrometer with a mean radius of 20 inches has been constructed. This instrument, a copy of the 16-inch spectrometer at the California Institute of Technology,[1] is to be used with the external beam from the Indiana cyclotron. It is mounted so that it can be rotated around the focal point of the beam focusing and analyzing magnet pair. A target chamber with a sliding O-ring seal allows this rotation to be made without breaking the vacuum connection between the cyclotron and the spectrometer. All angles from a minimum of 10° to maxima of 45° counterclockwise and 145° clockwise are available. Preliminary observations of the scattering of 21.5-Mev α-particles by carbon have been made. The elastic group and the inelastic groups corresponding to the first three excited states of C^{12} have been found at several angles, and it is has been noted that their intensity changes quite rapidly with angle. Observation of groups corresponding to higher states of C^{12} is more difficult because of their reduced intensity and because of the continuum due to $C^{12*} \rightarrow Be^8 + \alpha$; $Be^8 \rightarrow 2\alpha$.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Snyder, Rubin, Fowler, and Lauritsen, Rev. Sci. Instr. **21**, 852 (1950).

J6. Gamma Rays from the Reaction $P^{31}(p\gamma)S^{32}$. H. E. GOVE AND E. B. PAUL, *Chalk River Laboratories.*—The gamma-rays from this reaction have been studied for proton energies between 1.03 and 2.1 Mev. The gamma-rays were detected in a NaI crystal 2 in. in diameter by 2 in. long and a 5819 photomultiplier. Fifteen resonances were observed in the energy range studied. Eleven of these below 1.65 Mev have been observed previously.[1] At three resonances the gamma-transitions to the ground and first excited states of S^{32} have been studied. At 1.17 and at 1.27 Mev the transitions to the first excited state exceed that to the ground state by at least a factor of 10. The angular distributions indicate $J=2\pm$ for both capturing states if the first excited state of S^{32} is assumed to be 2+. At 1.90 Mev the transition to the first excited state is less than a seventh of that to the ground state and the angular distribution indicates 1− for this resonance.

[1] Grove, Cooper, and Harris, Phys. Rev. **80**, 107 (1950).

J7. Excitation Levels of Li^7 and F^{19} by Betatron Irradiation. J. GOLDEMBERG AND L. KATZ, *University of Saskatchewan.*—The neutron yield from Li^7 and F^{19} has been measured as a function of the operating energy of the University of Saskatchewan betatron. Counting statistics were held to one percent accuracy, and it is believed that the betatron energy was controlled to better than ±5 kev. The neutron yield curves were found to exhibit breaks which are interpreted as excitation levels in the nuclei irradiated. The breaks were found at: Levels of Li^7: 9.6, 10.8, 12.4, 14, 17.5 Mev. Levels of F^{19}: 11, 11.5, 11.9, 15.3 Mev. Good agreement was found with previously measured levels. The two elements were compared in the region 13 to 15 Mev, where it was clearly demonstrated that a break is present in Li^7 but not in F^{19}.

J8. Fine Structure in the $C^{12}(\gamma,n)C^{11}$ Neutron Yield. L. KATZ AND J. GOLDEMBERG, *University of Saskatchewan.*—The neutron yield resulting from the reaction $C^{12}(\gamma,n)C^{11}$ when carbon is irradiated in the University of Saskatchewan betatron has been examined as a function of the betatron operating energy. This curve was found to consist of a number of straight line portions. These discontinuities in the curve are attributed to photonuclear absorption by individual levels in C^{12}. Measurements of residual activity taken one year apart[1] and the neutron yield results are in excellent agreement with each other and with levels found in $B^{11}(p,n)C^{11}$ experiments. The breaks were found at 19.3, 19.7, 20.1, 20.5, 20.7, 21.1, 21.6, 22.4, and 22.8 Mev. Energies are measured relative to the threshold for this reaction at 18.7 Mev obtained from mass data.

[1] Haslam, Katz, Horsley, Cameron, and Montalbetti, Royal Society Canada, June Meeting, 1952.

Post-Deadline Papers, if Any

FRIDAY AFTERNOON AT 2:00

Upper Strong Auditorium

(J. A. WHEELER presiding)

M1. McGill, Fifty Years after Rutherford and Soddy. J. S. FOSTER, *McGill University.* (40 min.)

M2. The Double Scattering of Protons. C. L. OXLEY, *University of Rochester.* (30 min.)

Nuclear Physics

M3. Apparatus for Double Scattering of 240-Mev Protons. W. F. CARTWRIGHT, C. L. OXLEY, J. ROUVINA, E. BASKIR, D. KLEIN, J. RING, AND W. A. SKILLMAN, *University of Rochester.*—Apparatus has been developed to measure polarization effects in proton scattering by observing asymmetries in double scattering. The first scatter is from a target in the circulating cyclotron beam. Protons scattered at 27 degrees are collimated, selected roughly in

energy, and passed into the second scattering apparatus outside the cyclotron vacuum tank. This apparatus is rigidly mounted in a cylindrical can rotatable about an axis that can be made to coincide with the direction of protons from the first scatterer. The useful beam is defined by a cylindrical scintillation counter on the axis. The second scattering is a p-p scatter detected by quadruple coincidences between the beam defining counter, a two-counter telescope detecting the protons scattered in a range about 27 degrees, and a counter for the lower energy recoil. An exploratory crystal 15 inches behind the beam defining crystal is used in coincidence with it to align the beam with the mechanical axis. The polyethelene scatterer is replaced with carbon to evaluate backgrounds. The targets and beam defining counter are optically set on axis. A magnetic shield prevents appreciable distortions of the proton paths.

M4. On the Temperature Dependence of BF_3 Proportional Neutron Counters.* FRANK R. WOODS, EDGAR F. BENNETT, AND JOHN A. LOCKWOOD, *University of New Hampshire.*—A study of the temperature dependence of commercial BF_3 neutron counters has been made during the past year. The tubes were enclosed in a temperature controlled jacket separated from an independent temperature regulated moderator by a vacuum chamber. The voltage pulse-height distributions with a Ra-Be neutron source at a fixed distance were investigated for various tube temperatures and moderator temperatures. The shape of the voltage pulse-height distributions was not affected by changes in moderator temperature, but the integrated counting rate decreased slightly with increased moderator temperature. This could be accounted for by the change in energy of the neutrons incident on the tube. There was a large decrease in the average pulse height with increase in tube temperature, as in agreement with Goodwin and Iona.[1] On analysis this was found to be due to the increased formation of negative ions in the pulse. With a fixed discriminator setting the temperature dependence in some cases was as high as 0.3 percent °C.

* Supported by the Geophysical Research Division, Air Force Cambridge Research Center.

[1] A. Goodwin, Jr., and M. Iona, Phys. Rev. **88**, 168A (1952).

M5. A Fast-Neutron Spectrometer Using the T(d,n) Alpha-Reaction. G. K. O'NEILL,* *Cornell University.*—A time-of-flight spectrometer has been developed which takes advantage of the D+T reaction mechanics to achieve a low background and good resolution. 110-kev deuterons from the Cornell cyclotron are brought out to a tritium-zirconium target. A thin stilbene crystal, shielded from scattered deuterons by a thin foil and from tritium betas by a magnetic field, detects the 3.5-Mev alpha-particle emitted in the reaction. The position of the crystal is so chosen that a photomultiplier viewing it delivers a timing pulse only when a neutron starts on a path free, for several meters, of all matter but air and the desired scattering material. Knowledge of the neutron's time-zero is limited only by the associated electronics and by variations in the path-length and energy of the alpha-particle. Contributions of the latter are calculated to be less than 10^{-9} second. The device does not require a pulsed source and wastes almost none of the available ion-beam. Experimental neutron-alpha coincidence curves as a function of neutron detector position and delay will be shown.

* U. S. Atomic Energy Commission Predoctoral Fellow.

M6. Quadrupole Focusing Lenses for Charged Particles. BRUCE CORK AND EMERY ZAJEC, *University of California, Berkeley.*—A set of four strong focusing magnetic quadrupole lenses has been constructed and operated. Each lens consists of four air-cooled electromagnets with pole tips having a hyperbolic cross section. The aperture of each lense is 2 in. in diameter, and the length is 4 in. Measurements of the magnetic field demonstrate that the hyperbolic cross section satisfies the requirements of a constant magnetic field gradient very well. The technique of deflecting a current carrying flexible wire has been used to measure the trajectory of charged particles through the system of lenses. It has been observed that the strong focusing requirements are satisfied. The system of lenses was then used to focus 0.5-Mev protons, 20-Mev deuterons, and 40-Mev alpha-particles. The parallel beam of 0.5-Mev protons was detected by observing the incandescence of a quartz plate while the protons were bombarding it. The focused beam was less than 1 mm in diameter. The astigmatic 20-Mev deuteron beam from the 60-inch cyclotron was increased in current density by a factor greater than 30.

M7. A High Yield Radio-Frequency Ion Source.* HAROLD P. EUBANK, *Brown University.*—An investigation of the operating characteristics of an rf ion source has been made with the ultimate purpose of obtaining sufficient ion current to render feasible the study of (n,p) reactions. To date the source has yielded up to 15 ma of ion current of which 80 to 90 percent consist of atomic ions. The dependence of the ion current upon the operating parameters of the source—pressure, rf power, and extracting voltage—has been measured throughout the available ranges. Although the density of ionization is found to increase steadily with both pressure and power, the ion current exhibits a clearly defined maximum within the range of each of the parameters employed. This is interpreted in terms of the potential distribution about the face of the exit canal which under proper conditions can yield considerable focusing of the ion beam prior to extraction.

* This work was supported in part by the U. S. Atomic Energy Commission.

M8. Bremsstrahlung and Electron Scattering Cross Sections in Au for 247-Mev Electrons and Positrons.* PHILIP C. FISHER, *University of Illinois.*—The absolute cross sections for gold for the top 40 percent of the bremsstrahlung spectrum have been measured for electrons and positrons of 247-Mev mean energy with the aid of a magnetic cloud chamber. With the possible exception of the top 2 percent of the spectrum, electrons and positrons give the same result. The Bethe-Heitler[1] spectrum is at least 8.7±2.7 percent above the experimental spectrum. The Maximon, Bethe, and Davies[2] theory agrees with experiment. Scattering by electrons was also observed as a function of energy of the struck or lowest energy electron. For these particles having energies between 20 and 130 Mev, the scattering cross section ratios of experiment to theory are 0.96±0.06 and 1.06±0.08 for incident electrons and positrons, respectively.[3, 4] The cross-sectional ratio of electrons to positrons in the same energy interval is 1.31±0.13 for experiment and 1.46 for theory. All errors are probable errors.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

[1] H. Bethe and W. Heitler, Proc. Roy. Soc. (London) **146**, 83 (1934).
[2] Maximon, Bethe, and Davies, Phys. Rev. **87**, 156 (1952).
[3] C. Møller, Ann. Physik **14**, 531 (1932).
[4] H. Bhabha, Proc. Roy. Soc. (London) **154**, 195 (1936).

FRIDAY AFTERNOON AT 2:00

Lower Strong Auditorium

(R. L. SPROULL presiding)

Field Emission

N1. New Methods of Field-Emission Microscopy. E. W. MUELLER, *Pennsylvania State College.* (30 min.)

N2. Field Emission from Oxygen on Tungsten. J. A. BECKER, *Bell Telephone Laboratories.* (30 min.)

N3. Field Emission and Chemisorption. ROBERT GOMER, *University of Chicago.* (30 min.)

N4. High Density Field-Emission Phenomena. W. P. DYKE, *Linfield College.* (30 min.)

Contributed Paper

N5. The Field Emission Microscope Investigation of Surface Reactions.* RALPH KLEIN, *Bureau of Mines.*—The field emission microscope[1] is a valuable tool for investigating surface reactions because events are revealed on a molecular scale, the state of the surfaces can be well defined, work functions can be easily measured, and differences of reaction on different crystal planes are readily observed. The reaction of carbon with oxygen on tungsten has been studied using this method. The average work functions over the emitting point show that the work function of a carbon-on-tungsten surface differs very little from that of clean tungsten, regardless of the amount of carbon present. Differences in the work functions of various oxgen-on-tungsten surfaces give an indication of relative surface coverages. Comparison of the pattern changes after heating an oxgen-carbon-on-tungsten surface with those of the surfaces oxgen-on-tungsten and carbon-on-tungsten suggests that the rate controlling step in the reaction is the breaking of the W—O bonds of the chemisorbed oxygen.

* This research is a part of the work being done at the Bureau of Mines supported by the Flight Research Laboratory, Wright Air Development Center.

[1] E. W. Müller, Physik. Z. **37**, 838 (1936).

FRIDAY AFTERNOON AT 2:00

Biology Lecture Room

(J. B. PLATT presiding)

P1. Mechanism of Evaporation of Liquids. K. C. D. HICKMAN, *Eastman Kodak Company.* (45 min.)

FRIDAY EVENING AT 7:00

Hotel Seneca

(G. B. PEGRAM presiding)

Banquet of the American Physical Society

After-Dinner Speech

"How Are We Training Our Scientists?" W. A. NOYES, *University of Rochester*

SATURDAY MORNING AT 10:00

Upper Strong Auditorium

(H. D. SMYTH presiding)

Nuclear Reactors

Q1. Possible Designs for an Economical Power Reactor. J. J. GREBE, *Dow Chemical Company.* (30 min.)

Q2. Current Status of the Theory of Reactor Dynamics. W. K. ERGEN, *Oak Ridge National Laboratory.* (30 min.)

Q3. The Thermal Test Reactor of Knolls Atomic Power Laboratory. LEWI TONKS, *Knolls Atomic Power Laboratory.* (30 min.)

Q4. Experience with the NRX Reactor. W. B. LEWIS, *Chalk River Laboratories.* (30 min.)

SATURDAY MORNING AT 10:00

Biology Lecture Room

(P. G. BERGMANN presiding)

Cosmic Rays; Theoretical Physics

R1. Emulsion Cloud-Chamber Study of High Energy Radiation at Mountain Altitude.* J. Z. KLOSE, M. F. KAPLON, D. M. RITSON, AND W. L. WALKER, *University of Rochester.*—An emulsion cloud chamber consisting of 24 alternate 6 in. × 4 in. 3.13-mm Pb plates and 250μ Ilford G-5 emulsions was exposed for one month at Echo Lake, Colorado. Using techniques similar to those in previous studies,[1] high energy nuclear interactions and electronic showers were detected and studied. From the analysis of the nuclear showers (median energy $\sim 10^{12}$ ev) an absorption mean free path in atmosphere of the high energy interacting component is derived. The value obtained, $\lambda_A \sim 120$ g/cm^2, is appreciably longer than the geometric mean free path. The flux and zenith angle distribution of the electronic showers will be discussed.

* Supported by U. S. Air Force, Air Research Development Command.
[1] M. F. Kaplon and D. M. Ritson, Phys. Rev. **88**, 386 (1952).

R2. Interactions of Heavy Primaries of the Cosmic Radiation.* M. F. KAPLON, J. H. NOON, AND D. M. RITSON, *University of Rochester.*—In tracing 300 heavy primaries 90 interactions were found with nuclei of a photographic emulsion "block." The emulsion "block" was composed of 92 400-micron stripped emulsions (6 in. × 4 in.) piled above each other. The block had been flown for six hours at White Sands (41° geomagnetic). Eight of the 90 interactions found appeared to be with the hydrogen of the emulsion. These can be used for charge calibration. Out of the 90 interactions 22 fragments with $Z=3$, 4, or 5 were found to emerge, confirming previously published values.[1] Thus it does not seem possible to account for an apparently observed primary flux of these nuclei[2] in terms of secondaries produced in the atmosphere. A detailed discussion of mean free paths and mechanism of the interactions will be presented at the meeting.

* Supported by U. S. Air Force, Air Research Development Command.
[1] H. L. Bradt and B. Peters, Phys. Rev. **80**, 943 (1950).
[2] Dainton, Fowler, and Kent, Phil. Mag. **43**, 729 (1952).

R3. Total Cross Sections for Positive Pions in Hydrogen. STANLEY L. LEONARD AND DONALD H. STORK, *University of California, Berkeley.*—The total cross section for positive pions scattered at angles greater than 35° in liquid hydrogen has been measured for pions of energies 33, 45, 56, and 69 Mev. Pions were identified by pulse height and Hp. The measured cross section at 33 Mev is 7.9±2.2 mb. A "liquid hydrogen in−liquid hydrogen out" subtraction was performed, and the pion flux has been corrected for muon contamination. In addition, a correction has been made for those pions which decayed after passing through the pulse-height counters and give rise to muons of such low energy that they reached the end of their range in the target. These pion decays were indistinguishable from true attenuation events. This correction amounted to about 9 mb at 33 Mev. Low energy muons resulting from pion decays ahead of the pulse-height crystals were readily distinguished from the pions by the pulse-height analysis. Analysis of data leading to values for the cross section at 45, 56, and 69 Mev is now in progress and these results will also be presented.

R4. Tamm-Dancoff Theory of Pion Photoproduction.* MARC ROSS, *Cornell University.*—The differential cross sections for the production of positive and neutral π-mesons by 311-Mev photons on protons have been calculated. The electromagnetic interaction is treated in perturbation theory. Matrix elements are evaluated between definite initial and final states. The wave functions for the final (meson plus nucleon) states are solutions of integral equations derived in the Tamm-Dancoff approximation using PS, PS meson theory.[1] The $s_{\frac{1}{2}}$ $I_{\frac{1}{2}}$ and $p_{\frac{1}{2}}$ $I_{\frac{1}{2}}$ states are treated in Born approximation to avoid divergence difficulties. The initial state (nucleon system) is treated in perturbation theory. The coupling constant is fixed at $G^2/4\pi=17.5$ to yield an attractive scattering phase shift of 50° for the $p_{\frac{3}{2}}$ $I_{\frac{3}{2}}$ state at 160 Mev (−33° for $s_{\frac{1}{2}}$ $I_{\frac{3}{2}}$). The shape and magnitude of the π^0 production are in good agreement with experiment. The total cross section for π^+ production is about $\frac{2}{3}$ experiment; the angular distribution is peaked just slightly beyond 90°. The π^+ production would be in better agreement with experiment if the s state matrix elements were moderately increased; at present, however, an adequate treatment for the s states is not available. Inclusion of Pauli type anomalous moments in the electromagnetic interaction is considered. The resulting cross sections are too large.

* Sponsored by National Science Foundation.
[1] Dyson, Schweber, and Visscher, Phys. Rev. **90**, 372 (A) (1953).

R5. Phenomenological Analysis of Meson-Nucleon Scattering. A. E. WOODRUFF, *University of Rochester.*—The potential model for the S wave in pion-nucleon scattering first suggested by Marshak[1] has been extended to include the $I=\frac{1}{2}$ S state. The existing data for both $I=\frac{3}{2}$ and $I=\frac{1}{2}$ S phase shifts between 0 and 135 Mev can be roughly fitted by an attractive potential with a repulsive core for the $I=\frac{3}{2}$ S state and a purely attractive well for the $I=\frac{1}{2}$ S state. Since both experiment and theory indicate that the most important P phase shift is that for the $I=\frac{3}{2}$, $J=\frac{3}{2}$ state, the three total cross section on hydrogen (π^+ elastic, π^- elastic, π^- charge exchange) can be used to calculate the three phase shifts α_1, α_3, and α_{33}. The values of α_1 and α_3 which are thereby obtained from the recent measurements at Chicago,[2] Rochester,[3] and Columbia[4] fit the model for the S phase shifts, while the α_{33} phase shift follows a p^3 law. Calculations of the α_{33} phase shift using the integral equation of Dyson[5] performed by B. P. Nigam will also be presented and compared with the data, together with further investigations of the model.

[1] R. E. Marshak, Phys. Rev. **88**, 1208 (1952).
[2] Weaver, Lord, and Orear, Bull. Am. Phys. Soc. **28**, No. 3, 42 (1953).
[3] Barnes, Angell, and Perry, private communication.
[4] Bodansky, Sachs, and Steinberger, preprint.
[5] Third Annual Rochester Conference Proceedings, December, 1952, p. 77.

R6. Effects of Certain Three-Body Nuclear Interactions in H^3 and He^3.† A. W. SOLBRIG, JR., *Vanderbilt University** (introduced by Ingram Bloch).—This limited, theoretical study is phenomenological and nonrelativistic. Effects of interactions on wave functions, magnetic dipole moments, and binding energies are obtained by first-order perturbation methods. The interactions satisfy well-known requirements of invariance, contain no power of momentum higher than the first, involve no dependence on charge, and introduce only P state in a first-order calculation. They con-

tain spin-orbit interactions and may give rise to interaction moments. Each interaction contains a scalar radial function of positions f. The unperturbed potential corresponds to pairwise Hooke's law forces between nucleons. The first-order energy perturbation is shown to vanish for all the interactions. It is shown, without further specialization of the f, that no one of fifty-eight of the seventy-five interactions yields observed magnetic moments. No definite conclusion is obtained for eleven of the remaining seventeen interactions, for calculations with plausible f appear difficult. Each of the remaining six interactions yields observed magnetic moments with plausible f.

† Work performed, in part, under U. S. Atomic Energy Commission Predoctoral Fellowship.
* Now at Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

R7. Implications of Lorentz Invariance for the Scattering of Spin 1/2 Particles.* DAVID FELDMAN, *University of Rochester*.—The most general matrix element M for the scattering of spin ½ particles which is invariant under the group of Lorentz transformations (including spatial reflections) can be expressed as the sum of ten types of terms (these may be classified as S, V, T, PV, PS with or without exchange); further considerations of charge conjugation and time inversion lead to nothing new. For the purpose of effecting a transition to the nonrelativistic limit as well as for convenience in investigating polarization effects at all energies, it is useful to transform the free-particle Dirac spinors into a two-component form using the method of Foldy and Wouthuysen. Under these circumstances, M assumes a structure which is identical with that which has already been given previously by several authors[1] who, in their derivations, restricted themselves from the very beginning to the nonrelativistic domain and who had to assume explicitly the invariance of the S matrix with respect to time inversion. The various theorems on polarization effects[1] that follow from the structure of M hence all stem directly from the requirements of Lorentz invariance. Similar considerations are being made to determine the consequences for the nonrelativistic two-nucleon potentials.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] L. Wolfenstein and J. Ashkin, Phys. Rev. **85**, 947 (1952); R. H. Dalitz, Proc. Phys. Soc. (London) **A65**, 175 (1952).

R8. "Fusion" Theory of Bosons and Nonlocal Field. SATOSI WATANABE, *U. S. Naval Postgraduate School*.—The nonlocal nature of boson fields is attributed to the internal structure of bosons as suggested by de Broglie-Heisenberg's depiction[1] of these particles as combinations (fusion) of spinor particles. A mathematical formalism is developed to implement such correlation of the nonlocal theory for bosons to the fusion theory. As an illustration, the case will be examined in which the resulting nonlocal equations turn out to be identical with those of Yukawa,[2] except for one new equation,

$$[x_\mu[x^\mu, U]]-\lambda^2 U+(1/64)\lambda^4\{P_\mu\{P^\mu, U\}\}=0,$$

replacing the one in Yukawa's theory which differs from this by the absence of the third term. The curved brackets here mean an anticommutator, and $\hbar=1$.

[1] L. de Broglie, Compt. rend. **198**, 135 (1934) and subsequent papers; W. Heisenberg, Z. Naturforsch. **5a**, 251 (1950) and subsequent papers.
[2] H. Yukawa, Phys. Rev. **77**, 219 (1950); **80**, 1047 (1950).

R9. Grand Canonical Ensembles, Laplace Transform, and the Darwin-Fowler Contour Integrals.* PETER G. BERGMANN AND EZRA NEWMAN, *Syracuse University*.—Let the Hamiltonian of a thermodynamic system depend on some parameter (s) such as volume or number of particles. Then the mean of the partial derivative of the Hamiltonian with respect to such a strain parameter represents the associated stress. If we combine ordinary (petit) canonical ensembles with different values of the strain parameter, weighting each ensemble with an appropriate exponential factor, then this Laplace transformation leads to the grand canonical ensemble. This transition interchanges, in a certain sense, the respective roles of strain and stress. A return to the petit ensemble is possible, by means of an inverse Laplace transformation, the integration to be carried out in the complex plane. The well-known Darwin-Fowler method for obtaining partition functions for fixed particle numbers is precisely such an inverse Laplace transformation. We are attempting to apply these methods to nonequilibrium situations.

* Supported by Office of Scientific Research, U. S. Air Force.

R10. Inertia as a Consequence of Wave Properties. RICHARD SCHLEGEL, *Michigan State College*.—Masses are usually determined by their gravitational or inertial effects. In principle, however, the individual mass value of a group of similar particles may be determined from deBroglie wavelength observations. We consider the deBroglie equation (1) as an empirical equation relating velocity, wavelength, Planck's constant h, and a mass parameter m. This equation, with the Lorentz transformations (2) and assumption of a frequency $\nu=E/h$ (3) associated with energy E, yields $E=mc^2$ (by inverting usual derivation of deBroglie's equation). Also, from the Lorentz transformations, $\nu'=\nu_0(1-v^2/c^2)^{\frac{1}{2}}$, (4), where ν_0 is frequency of some point process at rest and ν' the frequency for an observer with relative velocity v. Equation (4) and $E=h\nu=mc^2$ give $m'=m_0/(1-v^2/c^2)^{\frac{1}{2}}$, (5), which has then been derived from equations for wave properties, (1), (2), and (3), with no assumption of momentum conservation or other inertial properties. From (5), and energy change defined as $\int_0^s F\cdot ds$ for arbitrary force F and displacement s, we readily get Newton's second law. We thereby may present inertia as a consequence of wave properties rather than as a primitive concept. Equation (5) is seen as resting on the frequency change (4) resulting from the Lorentz transformation.

R11. Description of Quantum States through Distributions of Observable Values. NORBERT WIENER AND ARMAND SIEGEL, *M.I.T.*—Quantum-mechanical states may be characterized by distributions of the allowable values of observables over differential space,[1] a generalized form of Hilbert space. Mean values are then calculated by use of a weighting factor; this is equivalent to the assignment of measure to sets of points in Hilbert space. We use the ensemble of idealized complex Brownian motion functions[2] $X(\alpha,x)$, where x is analogous to the time in the experimentally observed Brownian motion, X is the (complex) displacement, and α is a parameter identifying an individual function of the set of all such Brownian motions, and thus identifying points in differential space. The wave function $\phi(x)$ is transformed to a function of α by the formal Stieltjes integral $\psi(\alpha)=\int\langle dX\rangle(\alpha,x)\phi(x)\cdot x(\alpha)$. The value of x belonging to the point α is then determined by an infinite sequence of dichotomies or polychotomies of the range of integration, by an algorithm that will be given. Since the time variation of $\psi(\alpha)$ is given by a point transformation of α, the method is closely related to the Gibbsian method of statistical mechanics.

[1] N. Wiener, J. Math. and Phys. **2**, 131 (1923).
[2] N. Wiener, Acta Math. **55**, 117–258 (1930); Paley and Wiener, *Fourier Transforms in the Complex Domain* (Am. Math. Soc., 1934), Chapter 9.

SATURDAY MORNING AT 10:00

Lower Strong Auditorium

(S. MROZOWSKI presiding)

Solid State Physics, III

S1. Current-Voltage Characteristics of Cadmium Sulfide Crystals Using Ohmic Contacts. R. W. SMITH AND A. ROSE, *RCA Laboratories Division.*—Cadmium sulfide crystals can be made with a wide range of resistivities and photosensitivities. The electrode material making contact to these crystals determines in large part the current-voltage characteristics observed. Electrodes of silver, copper, gold, platinum, and graphite usually give rectifying contacts. Cadmium sulfide is an *n* type semiconductor. It has now been found that indium and gallium make low resistance, ohmic contacts to cadmium sulfide crystals throughout their resistivity range from 10 to 10^{12} ohm-cm. Using one indium and one silver electrode on low resistivity cadmium sulfide crystals large area rectifiers have been made. Current densities of over one amp/sq cm in the forward direction with a few volts applied and a front to back current ratio of 10^7 were observed. The ohmic contacts appear to be completely free from the photovoltaic effects observed with rectifying contacts. The ohmic contacts permit efficient photoconductive performance at low voltages. Quantum gains of 10^4 (corresponding to over 10 amperes per lumen) have been obtained with only 10 volts applied across a crystal 10^{-3} cm thick. The ohmic contacts enable significant currents (over 10^{-2} ampere per sq cm) to be passed through thin insulating crystals in the dark. The dependence of these currents on ac and dc voltages suggests that they are space-charge-limited currents due to injected carriers from the cathode.

S2. Space-Charge-Limited Currents in Insulators. A. ROSE AND R. W. SMITH, *RCA Laboratories.*—A trap-free insulator should be able to pass relatively large space-charge-limited currents if one electrode supplies a reservoir of free charge carriers. Such currents should increase as the square of the applied voltage. Current-voltage curves of this form have been reported through thin layers of amorphous selenium illuminated by strongly absorbed light at one electrode. These currents, however, are orders of magnitude lower than would be expected for any reasonable value of carrier mobility. Shallow traps can account both for the low magnitudes of current and for the retention of the square law dependence on voltage. Currents of a space-charge-limited nature, drawn through thin crystals of CdS in the dark, are reported in a companion paper.[1] These currents by contrast have been observed to increase nearly exponentially with applied voltage. Such an exponential rise may be derived from the assumption of traps distributed continuously in energy. The magnitude of these currents was used to estimate a volume density of traps of the order of 10^{19} cm^{-3}. The use of space-charge-limited currents should be a powerful tool for measuring the perfection of crystals since the ease of making observations improves as the trap density becomes vanishingly small.

[1] R. W. Smith and A. Rose, Abstract No. S1.

S3. Some Noise Observations on CdS Crystal Photoconductors. CARL SHULMAN, R. W. SMITH, AND A. ROSE. *RCA Laboratories.*—Cadmium sulfide crystals with indium or gallium electrodes show noise powers which are orders of magnitude less than those measured in CdS with silver electrodes. Furthermore, crystals have been found in which the noise spectrum is observed to flatten off at low frequencies. However, for most crystals the noise power is proportional to the incident light intensity and to the square of the voltage across the crystal. It is suggested therefore that, to a first approximation, the noise can be understood in terms of a photomultiplier model[1] in which the noise current is given by the expression $\bar{i}^2=2eGI\Delta f$, where G is the gain of the crystal or the ratio of photocurrent to photon current. G may be greater or less than unity and is proportional to the applied voltage and carrier life time. Δf is understood not to exceed the speed of response of the crystal. Values of G determined from noise measurements check order of magnitude of actual measured gains.

[1] B. Davydov and B. Gurevich, J. Phys. (U.S.S.R.) **7**, 138 (1943).

S4. The Seebeck Effect in Germanium. T. H. GEBALLE, *Bell Telephone Laboratories.*—The Seebeck effect in germanium has been investigated by previous workers.[1] In this investigation, the Seebeck and Hall effects have been measured from liquid hydrogen temperatures to the intrinsic region for a series of *n* and *p* type single crystals. It has been shown[2] quite generally that in a thermoelectric circuit the Seebeck voltage per degree Q is equal to the entropy convected through the circuit per unit current. When the usual band scheme is assumed, the entropy convected by unit current is simply $\Delta E_F/T$ plus a term involving kinetic energy transported by electrons. ΔE_F is the distance of the Fermi level from the band edge. ΔE_F determined from Seebeck voltage agrees with ΔE_F determined from Hall voltage in order of magnitude down to about 200°K. As the temperature is lowered still further, the Seebeck voltage becomes increasingly too large, reaching a maximum just above the hydrogen boiling point. It appears that an additional mechanism other than electron transport of entropy must be considered in order to relate the observed data. This is considered in the next paper by C. Herring.

[1] H. P. R. Frederikse, Phys. Rev. **86**, 647 (1952); Lark-Horovitz, Middleton, Miller, Scanlon, and Wallerstein, Phys. Rev. **69**, 259 (1946); V. A. Johnson and K. Lark-Horovitz, Bull. Am. Phys. Soc. **28**, No. 2, 32 (1953).
[2] C. Herring, Phys. Rev. **59**, 889 (1941); C. Herring and M. H. Nichols, Revs. Modern Phys. **21**, 185 (1949).

S5. Theory of Thermoelectric Power of Semiconductors. CONYERS HERRING, *Institute for Advanced Study and Bell Telephone Laboratories.*—The usual theory of thermoelectric power cannot explain the marked rise in the numerical magnitude of this quantity observed by Geballe for high resistivity germanium specimens at moderately low temperatures. It is proposed that this rise is due to the existence of appreciable assymmetry in the distribution of phonons in lattice momentum, this assymmetry occurring whenever the processes restoring randomness of phonon motions become sufficiently slow. The effect may be described either as a drag exerted on the electrons or holes by the thermal conduction phonon current, or, equivalently, as a contribution to the Peltier heat flow in an isothermal specimen, due to phonons dragged along by the electric current. Over a considerable range of temperatures T and carrier concentrations n the additional thermoelectric power ΔQ should be independent of n and roughly proportional to T^q, where q is in the neighborhood of 2.5. However, at very low T or at very large n, ΔQ should decrease toward zero, because at low T

the phonon distribution becomes governed by boundary scattering and because for large n a saturation effect should occur. The absolute magnitude of the effect can be roughly predicted from thermal conductivity data.

S6. Measurement of Charge Multiplication in Germanium and Sicilon p-n Junctions. K. B. McAfee and K. G. McKay, *Bell Telephone Laboratories.*—Previous measurements[1] have shown that carriers injected into narrow p-n junctions biased at greater than the critical field strength do not multiply in crossing such barriers. Present measurements describe the effect of extending the portion of the characteristic studied into the precritical region. Three separate methods of injection of carriers were employed. These were (1) photo injection; (2) injection by α-particles; and (3) injection by transistor action. The results show definite charge multiplication by a factor of almost 20 as the critical voltage is approached. Very similar results are obtained in comparing the three injection methods. α-particle bombardment sets the time scale of the multiplication process at less than 0.02 microsecond in both germanium and silicon. Both electrons and holes show approximately the same multiplication at equal field strengths. Examination of the results using the Townsend β-mechanism as a model and assuming that holes and electrons have very similar ionization coefficients yields resonable values for the ionization rates for holes and electrons at room temperature. It is concluded that both electrons and holes ionize in germanium and silicon junctions, at field strengths of approximately 10^5 and 2×10^5 volts/cm, respectively, a fact casting some doubt on the applicability of the Zener theory.

[1] McAfee, Ryder, Shockley, and Sparks, Phys. Rev. **83**, 650 (1951).

S7. Theory of Low Temperature "Breakdown" Effect in Germanium. N. Sclar, E. Burstein, and J. W. Davisson, *Naval Research Laboratory.*—The field dependent electrical breakdown in germanium[1] is attributed to the impact ionization of neutral impurities by free charge carriers. Debeye's data[2] on the Hall mobility of electrons shows that lattice vibration scattering is dominant from 300°K down to 11°K for samples with resistivities greater than about 2 ohm-cm. The critical field for the onset of breakdown is accordingly calculated by setting the rate at which the charge carriers lose energy to the lattice vibrations equal to the rate at which they gain energy from the field and requiring their kinetic energy to be equal to the ionization energy (ΔE) of the impurities. This gives

$$E=[2(\Delta E)c(m^*/kT)^{\frac{1}{2}}]/lq,$$

where c is the velocity of sound and l is the mean free path which varies as $1/T$. For n type germanium at 4.2°K, the results give E_{calc}=7.1 volts/cm with E_{obs}=6.4 volts/cm. Ryder obtains a discontinuity at $E\approx12$ volts/cm in the $E-J$ characteristic at 20°K which Conwell[3] attributes to an increase in mobility. It is suggested that this discontinuity may be due to impact ionization, for which the present theory gives E_{calc}=16 volts/cm.

[1] Sclar, Burstein, Turner, and Davisson, Bull. Am. Phys. Soc. **28**, No. 2, 17 (1953).
[2] E. M. Conwell, Proc. Inst. Radio Engrs. **40**, 1327 (1952).

S8. Faraday Rotation in Germanium. H. Suhl and G. L. Pearson, *Bell Telephone Laboratories, Inc.*—Measurements of Faraday rotation in germanium were made in the 1.25-cm band, at 77°K and magnetic field strengths to 16 kilooersteds. In an electron gas with collision frequency small compared with signal frequency, the rotation *versus* field curve rises to a maximum, then reverses rather steeply (at cyclotron resonance), and gradually returns to zero. Similar behavior would occur in germanium, if the energy-momentum surfaces were sufficiently simple and if the collision frequency was low enough. The ellipsoidal surfaces of Shockley[1] should give one, or two, such resonances, depending on sample orientation. From the corresponding field values, the effective masses can be computed. At 77°K, the mean free path is too small to give resonance, but information can still be gained by curve-fitting. Consider for simplicity a single effective mass m^* only. If m^* equalled m, we should have obtained resonance. The collision frequency equals the reciprocal mobility times e/m^*. Hence, the smaller m^*, the less the curves resemble the resonance curve. They reach an asymptotic form without reversal in rotation as m^*/m decreases to values less than the ratio: (collision frequency with $m^*=m$)/(signal frequency). Our measurements on n type place us close to this region, indicating $m^*<0.3m$ in at least one orientation.

[1] W. Shockley, Phys. Rev. (to be published).

S9. Temperature Dependence of Electron Mobility in AgCl.* Frederick C. Brown, *Reed College.*—Improved crystal counter techniques[1] have been used to measure the absolute values of drift mobility for electrons in AgCl from liquid nitrogen to dry ice temperatures. Measurements were made on single crystals grown from the melt which were relatively free from impurities and in which the electrons had long drift paths. A fast amplifying system was employed that could be used with a rise time less than 0.015 microsecond when necessary. The shape of the conduction pulses for energy released by beta-particles is shown to be useful in indicating the saturation condition required for the mobility determination. Preliminary results on a limited number of samples as well as consideration of the data of Haynes and Shockley[2] indicate a $T^{-3/2}$ dependence on temperature as predicted by electron interaction with acoustical modes of vibration at the lower temperatures.

* Supported by grants from the Research Corporation and the National Science Foundation.
[1] R. Hofstadter, Nucleonics **4**, No. 5, 29 (1949).
[2] J. R. Haynes and W. Shockley, Phys. Rev. **82**, 935 (1951).

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